

VOLTAGE-IMPRESSED CURRENT MEASURING APPARATUS AND
CURRENT BUFFERS WITH SWITCHES USED THEREFOR

Technical Field

5 This invention pertains to a voltage-impressed current measuring apparatus of a semiconductor test apparatus and current buffers with switches used therefor, for which miniaturization, or the design into an MCM (Multi Chip Module), or an IC (Integrated Circuit), of the analog circuitry is possible.

10 Prior Art

 In Japanese Patent Application Kokai Publication No.5-119110, there is set forth a direct-current measuring device used in direct-current tests of an IC measuring apparatus and set up to supply a set constant current or a constant voltage to a load (device under test, DUT) and to switch, in accordance with
15 the load current range, detection resistors detecting the voltage generated in the load or the current flowing in the load at that time.

 In Japanese Patent Application Kokai Publication No.8-54424, there is set forth a voltage-impressed current measuring apparatus in which the range-switching circuit is eliminated and higher speeds and a smaller size are
20 attained.

 In Japanese Patent Application Kokai Publication No.10-10162, there is set forth, in a current detection circuit as well as in a voltage-impressed current measuring circuit and a constant-current supply circuit using said circuit, a current detection circuit wherein the number of leak-proof relays
25 switching the current detection resistors has been reduced.

 Fig. 1A shows schematically the configuration of the conventional voltage-impressed current measuring circuit set forth in the aforementioned Japanese Patent Application Kokai Publication No.5-119110. Further,

voltage-impressed current measuring circuits shown in Fig. 1A are provided respectively for a plurality of measurement channels corresponding to a plurality of terminal pins of the semiconductor integrated circuit being the device under test, as is ordinary for semiconductor test apparatuses.

5 This voltage-impressed current measuring circuit has a DA (Digital to Analog) converter 10, resistances Ra and Rb, an operational amplifier A1, a current measuring portion 100, and a cable 5, impresses a desired test voltage Vs on a terminal of the device under test (DUT), and measures the current flowing in the same terminal by means of current measuring portion 100.

10 DA converter 10 receives the desired setting data DV to be impressed on the DUT from the exterior, and generates a corresponding direct-current reference voltage Vr. This reference voltage Vr is supplied to an inverted input terminal of operational amplifier A1 through resistance Ra.

15 Operational amplifier A1 is a power operational amplifier supplying a positive or negative direct-current voltage to the DUT, which receives said reference voltage Vr and, based on resistances Ra, Rb, controls by feedback via a feedback path Als that DUT terminal voltage Vs is at a prescribed fixed direct-current voltage. This voltage Vs can e.g. be expressed as $V_s = R_b \cdot V_r / R_a$. The output voltage Va of operational amplifier A1 is impressed on the
20 DUT terminal via current measuring portion 100. Further, the non-inverted input terminal of operational amplifier A1 is connected to circuit ground GND.

25 Current measuring portion 100 is a measuring portion measuring the load current of the DUT, which detects the current volume flowing to the DUT by measuring the voltage generated across the two ends of a resistance inserted in series, converts the voltage to a digital value, and supplies it as measurement data to a test apparatus, which is not illustrated. As for the current measurement range, a broad range from several μA to several tens of

mA is required. Because of this, current measuring portion 100 is provided with a range switching portion 110 and a potential difference measuring portion 150, as shown in Fig. 1B. Said range switching portion 110 is, as shown in Fig. 1C, provided with a plurality of n series resistances R_1 to R_n and switches SW_1 to SW_n , which are respectively connected in series to these resistances.

Since switches SW_1 to SW_n in range switching portion 110 are implemented with high input output isolation, they are composed of commercially available, discrete component photo MOS relays (semiconductor switches using photocouplers having MOS transistors in the output stage) and can be controlled to be switched ON/OFF by external control signals cnt_1 to cnt_n . In case photo MOS relays are used, the range switching time ranges from several hundred μs to several ms. Moreover, a switch drive current of approximately 10 mA is necessary.

As an example of a configuration of the internal circuit of potential difference measuring portion 150, there is a configuration wherein voltages V_c , V_d at the two ends of a series resistance R_i (i being an integer such that $1 \leq i \leq n$) selected by switch SW_i , as shown in Fig. 2, are received with high impedance by operational amplifiers A55, A56, and the potential difference V_x between the two ends is converted into a digital value. This circuit, set forth e.g. in United States Patent No. 6,255,839, enables setting $V_x = V_e$ by appropriately choosing the values of resistances R_{51} to R_{54} . Voltage V_e is converted into a digital value by an AD converter 59 and supplied to a test apparatus which is not illustrated.

As explained above, since switches SW_1 to SW_n switching measurements in a broad current range from several μA to several tens of mA are composed of discrete component photo MOS relays, if they are based on the prior-art range switching means used in voltage-impressed current

measurement circuits and the like, there is the drawback that it is not possible to miniaturize, or design into an MCM (Multi Chip Module) or an IC, all of the analog circuitry in the voltage-impressed current measurement circuits and the like. Moreover, there is also the drawback that the range switching
5 time is in the region of several hundred μ s to several ms. In addition, there is also the drawback that the drive current for the ON/OFF control requires approximately 10 mA.

Accordingly, it is an objective of the present invention to provide a voltage-impressed current measuring apparatus and current buffers with
10 switches used therefor, for which miniaturization, or the design into an MCM or an IC, of the analog circuitry is possible.

Disclosure of the Invention

According to this invention, a voltage-impressed current measuring apparatus which impresses a prescribed voltage and measures the current
15 flowing to a load apparatus, is configured so as to comprise

a current-range switching portion having: a plurality of pairs connecting in series a plurality of current buffers with switches, [the buffers] having output stages capable of being electrically connected or disconnected in response to a supplied control signal, and current measurement resistances
20 of differing resistance values respectively connected to the output stages of the current buffers with switches, wherein any one of the pairs is selected by a control signal to switch the current measurement range, said output stage of the current buffer with switch of said selected pair taken to be in a connected state;

25 a direct-current power supply portion, supplying a prescribed direct-current voltage to said load apparatus through the series connection of the current buffer with switch and current measurement resistance selected by said current range switching means; and

a potential difference measuring means, measuring, as a value corresponding to the current flowing in said load apparatus, the potential difference across the two ends of the current measurement resistance of said series connection due to the current which accompanies the impression of said direct-current voltage on said load apparatus and flows from the current buffer with switch of said selected series connection to said load apparatus.

According to this invention, the current buffers with switches [each] have a pre-stage portion and an output stage,

wherein said output stages have complementary first and second transistors which have their emitters mutually connected, the voltage of the same connection point taken to be the output voltage of said current buffers with switches, and their collectors connected respectively to a positive power supply and a negative power supply; and

wherein said pre-stage portions are configured so as to [each] comprise a first PNP transistor and a first NPN transistor, in which: the emitters are respectively connected to a first and a second constant-current supply; the collectors are respectively connected to a negative power supply and a positive power supply, the voltage from said direct-current power supply portion being supplied to the respective bases as the input voltage; and a first base voltage, the base emitter voltage added to said input voltage, and a second base voltage, the base emitter voltage subtracted from said input voltage, are supplied from the respective emitters to the bases of said complementary first and second transistors;

a second PNP transistor having a collector and an emitter connected respectively to the base of said complementary second transistor and said positive power supply; a second NPN transistor having a collector and an emitter connected respectively to the base of said complementary first transistor and said negative power supply; and

a control means, which, when said current buffer with switch is non-selected in response to said control signal, supplies to said first and second constant-current supplies a first and a second OPEN signal changing said first and second constant-current supplies to OFF, supplies a third and a fourth
5 OPEN signal to the bases of said second PNP transistor and said second NPN transistor putting the same transistors into the ON state, thereby holding said complementary first and second transistors of said output stage in the OFF state; and which, when said current buffer with switch is selected, supplies to
10 said first and second constant-current supplies a first and a second OPEN signal changing said first and second constant-current supplies to ON, and supplies a third and a fourth OPEN signal to the bases of said second PNP transistor and said second NPN transistor putting the same transistors into the OFF state, thereby putting said complementary first and second transistors of said output stage into the ON state.

15 Brief Description of the Drawings

Fig. 1A is a block diagram showing a configuration example of a conventional voltage-impressed current measuring circuit.

Fig. 1B is a theoretical block diagram of current measuring portion 100 in Fig. 1A.

20 Fig. 1C is a diagram showing a concrete configuration example of range switching portion 110 in Fig. 1B.

Fig. 2 is a diagram showing the internal circuit configuration of potential difference measuring portion 150 in Fig. 1B.

25 Fig. 3 is a block diagram showing an embodiment of a voltage-impressed current measuring apparatus according to the present invention.

Fig. 4 is a diagram showing a configuration example of current buffer with switch CBi in Fig. 3.

Fig. 5 is a circuit diagram showing a concrete circuit configuration example of pre-stage portion 11 and output stage 12 of current buffer with switch CBI in Fig. 4.

Fig. 6 is a diagram showing another configuration example of current
5 range switching portion 210 in Fig. 3.

Fig. 7 is a diagram showing yet another configuration example of current range switching portion 210 in Fig. 3.

Fig. 8 is a diagram showing a different configuration example of current range switching portion 210 in Fig. 3.

10 Best Mode for Implementing the Invention

Below, an embodiment of a voltage-impressed current measuring apparatus according to the present invention will be explained with reference to the figures. Moreover, neither is the scope of the patent claims limited by the explanation contents of the working mode mentioned hereinafter, nor are
15 the elements, connection relationships, or the like explained with the working mode necessarily required. In addition, the appearance / shape of the elements, connection relationships or the like explained with the working mode is an example and [the invention] is not limited to the same appearance / shape.

20 Further, like numerals are attached to elements corresponding to the conventional configuration, and the explanation of elements with like numerals is omitted except where needed.

Fig. 3 shows an embodiment of a voltage-impressed current measuring apparatus according to this invention. The voltage-impressed current
25 measuring apparatus is composed of a direct-current power supply portion 220 and a current measuring portion 200. Direct-current power supply portion 220 is composed of a DA converter 10, resistances Ra, Rb, and an operational amplifier A1, these performing the same operations as the corresponding parts

in Fig. 1A. Current measuring portion 200 is composed of a range switching portion 210 and a potential difference measuring portion 150. In this embodiment, the configuration of the circuitry of current range switching portion 210 is provided with a plurality of (n) current buffers with switches CB1 to CBn, and series resistances R1 to Rn for current measurement that are
5 respectively connected to the outputs of the same, as shown in Fig. 3.

Each current buffer with switch CBi (i being an integer satisfying $1 \leq i \leq n$) has an output stage making it possible to control it to be in an open state (electrically OFF state) by a control signal cnti supplied from the exterior (e.g.
10 a test apparatus which is not illustrated). The output stage of each current buffer with switch CBi is connected in series with a corresponding series resistance Ri.

The internal configuration of each current buffer with switch CBi includes, as shown e.g. in Fig. 4, a pre-stage portion 11 and an output stage
15 12. Pre-stage portion 11, together with operating as a current buffer, controls the ON/OFF switching of output stage 12 by control signal cnti from the test apparatus. Output stage 12 is composed of complementary configuration transistors and can be controlled to be ON/OFF in a high-impedance state by pre-stage portion 11, based on control signal cnti.

Fig. 5 is a concrete circuit configuration example of pre-stage portion 11 and output stage 12 of current buffer CB1 with switch. Pre-stage portion 11 is provided with differential transistors Q1, Q2, constant-current sources CC1, CC2, CC3, a control level conversion means 8, PNP transistors Q3, Q5, and NPN transistors Q4, Q6. Output stage 12 is provided with a PNP
25 transistor Q12 and an NPN transistor Q11 having their emitters mutually connected. The power supply uses a positive power supply VP and a negative power supply VN. An explanation will be given of the case where differential control signals cnt1a and cnt1b are used as external control signal cnt1.

The emitters of differential transistors Q1 and Q2 are respectively connected to constant-current source CC3, and their collectors are connected via control level conversion portion 8 to positive power supply VP.

Differential transistors Q1 and Q2 mutually become inverted to operate in
5 ON/OFF [states] by control signals cnt1 and cnt2, and control level conversion portion 8 outputs predetermined OPEN signals C1, C2, C3, C4 on the basis of the pair of the same states.

PNP transistor Q3 has an input voltage S_{in} (i.e. voltage V_a from direct-current power supply portion 220) supplied to its base, its emitter is connected
10 to constant-current source CC1, and its collector is connected to negative power supply V_N . Since a fixed current flows in PNP transistor Q3, based on constant-current source CC1, emitter terminal voltage V_{b11} becomes higher than input voltage S_{in} only by the base emitter voltage (approximately 0.6 V), and this [voltage] is supplied to the base input terminal of NPN transistor Q11
15 as a first base voltage.

In a similar way, NPN transistor Q4 has its base connected to the base of PNP transistor Q3, to which input voltage S_{in} is supplied. Since a fixed current is flowing, based on constant-current source CC2 connected to the emitter, emitter terminal voltage V_{b12} becomes lower than input voltage S_{in}
20 only by the base emitter voltage (approximately 0.6 V), and this [voltage] is supplied to the base input terminal of PNP transistor Q12 as a second base voltage. The collectors of PNP transistors Q5 and NPN transistor Q6, to whose bases OPEN signals C3, C4 are supplied, are respectively connected to the bases of transistors Q12 and Q11 and control the ON/OFF [operation] of
25 transistors Q12, Q11 by OPEN signals C3, C4.

NPN transistor Q11 and PNP transistor Q12 have a complementary configuration output stage, and in the state where constant-current sources CC1, CC2 are set to ON by OPEN signals C1, C2, both transistors ordinarily

operate in a state biased to the active state, based on said first base voltage Vb11 and second base voltage Vb12. Consequently, input voltage Vin is received and an output voltage Vout which is current buffered 1 : 1 is output.

As mentioned above, control level conversion portion 8 generates four
5 OPEN signals C1, C2, C3, C4 which control the output stage 12 to the OFF state based on external control signal, cnt1, and by supplying e.g. a fixed 1.5 V voltage to one differential control signal, cnt1b, and switching the voltage of the other differential control signal, cnt1a, between 0 V and 3 V, the desired control level OPEN signals C1, C2, C3, C4 are generated based on
10 this reverse operation, since the currents of differential transistors Q1, Q2 operate in reverse.

When first OPEN signal C1 becomes valid, the fixed current of constant-current source CC1 is controlled to be in the OFF state. When second OPEN signal C2 becomes valid, the fixed current of constant-current
15 source CC2 is controlled to be in the OFF state.

When third OPEN signal C3 becomes valid, PNP transistor Q5 is controlled to be in the ON state, and one [complementary transistor,] PNP transistor Q12 is forcibly biased to the OFF state. As a result of this, output voltage Vout can be supplied with high impedance, whatever the voltage
20 range, from positive power supply VP to negative power supply NP [VN?], and an open state can be maintained.

When fourth OPEN signal C4 becomes valid, NPN transistor Q6 is controlled to be in the ON state, and the other [complementary transistor,] NPN transistor Q11 is forcibly biased to the OFF state. As a result of this,
25 output voltage Vout can be supplied with high impedance, whatever the voltage range, from positive power supply VP to negative power supply VN, and an open state can be maintained.

Consequently, first, when it is desired to put output stage 12 into the active state (ON state), since it is necessary to bias final stage NPN transistor Q11 and PNP transistor Q12 to the active state, OPEN signals C1, C2 are controlled so that constant-current sources CC1, CC2 are put into the active state, and PNP transistor Q5 and NPN transistor Q6 are controlled to be in the OFF state. As a consequence of this, due to the cancellation of the two base emitter voltage drops of PNP transistor Q3 and NPN transistor Q11, a voltage V_{out} corresponding to input voltage S_{in} is output. In a similar way, due to the cancellation of the two base emitter voltage drops of NPN transistor Q4 and PNP transistor Q12, a voltage V_{out} corresponding to input voltage S_{in} is output. This is to say that the functioning is that of a normal current buffer. Here, if transistors Q3, Q4, Q11, Q12 are formed on the same IC in order to eliminate the manufacturing variations in said base emitter voltage drops, output voltage V_{out} can be considered to be at practically the same potential as input voltage S_{in} .

Second, when it is desired to put output stage 12 into the open state (OFF state), since it is necessary to put final stage NPN transistor Q11 and PNP transistor Q12 completely into the reverse bias state, OPEN signals C1, C2 are controlled so that constant-current sources CC1, CC2 are put into the OFF state, and PNP transistor Q5 and NPN transistor Q6 are controlled to be in the ON state. As a consequence of this, the circuit between the output terminal of output voltage V_{out} and output stage 12 is put in an open, electrically completely cut off state. Here, regarding NPN transistor Q11 and PNP transistor Q12, transistors are applied which have a breakdown voltage not producing any leakage current with respect to a base emitter reverse voltage bias.

Consequently, it is possible to configure range switching portion 210 shown in Fig. 3 by applying the aforementioned current buffer with switch

CB1 of Fig. 4. Because of this, by making the DUT load current flow to a desired series resistance $R1$ to Rn using external control signals $cnt1$ to $cntn$, it becomes possible to measure the current for each range by supplying two voltage signals, of output [input?] side voltage Va (detected voltage Vc) and load side voltage Vb (detected voltage Vd) which are detected based on said series resistance, to potential difference measuring portion 150. In this way, one can, for current buffers with switches $CB1$ to CBn , make a configuration with transistors, since the same circuit configuration elements are elements which can be made into IC or MCM, so a substantial miniaturization can be implemented. In addition, because the settling time of the ON/OFF control is less than several μs , the advantage can also be obtained that it becomes possible to switch with a remarkably high speed, compared to the past. Also, there is the advantage that, as regards the drive current required for the ON/OFF control, very little is sufficient.

Fig. 6 is another circuit configuration example of current range switching portion 210 in the embodiment of Fig. 3. This is a configuration example that cancels the influence on measurement errors of minute potential difference fluctuations that are generated together with the change in the load current volume between each input and output of current buffers with switches $CB1$ to CBn . This current range switching portion 210 is provided with a plurality of n current buffers with switches $CB1$ to CBn , series resistances $R1$ to Rn , and a multiple-contact switch 20 and, instead of detecting voltage Va on the input side of current buffers with switches $CB1$ to CBn in Fig. 3 as detected voltage Vc , it detects a voltage selected by multiple-contact switch 20 from among output side voltages $Va1$ to Van as detected voltage Vc .

Since the configuration based on current buffers with switches CB1 to CBn and series resistances R1 to Rn is the same as the aforementioned configuration in Fig. 3, its explanation will be omitted.

5 Multiple-contact switch 20 receives the voltage signals of one end of each series resistance R1 to Rn and, based on control signals cnt1 to cntn, selectively switches to and outputs one [of the signals]. A multiple-contact switch 20 such as this can be configured with transistor circuits which can be designed into an IC.

10 According to the aforementioned configuration in Fig. 6, there is the advantage that measurements can be performed without being subject to the influence of minute potential difference fluctuations which are generated together with changes in the load current volume between each input and output of current buffers with switches CB1 to CBn.

Fig. 7 is another circuit configuration example of current range
15 switching portion 210. This is a configuration example that cancels the influence on measurement errors of minute potential difference fluctuations that are generated together with the change in the load current volume between each input and output of current buffers with switches CB1 to CBn. This current range switching portion 210 is provided with a plurality of n
20 current buffers with switches CB1 to CBn, series resistances R1 to Rn, and a plurality of n current buffers with switches CB31 to CB3n.

Current buffers with switches CB31 to CB3n are switches transmitting voltage signals, which basically have one and the same internal configuration as the aforementioned current buffer with switch CB1 in Fig. 5. However,
25 since potential difference measuring portion 150 receives with high impedance, there is no need for current buffering, so it is acceptable to have only transmission of the voltage signal. Accordingly, they are not a main

cause of voltage drop errors like [those caused by] the aforementioned current buffers with switches CB1 to CBn.

According to the aforementioned configuration in Fig. 7, there is the advantage that measurements can be performed without being subject to the influence of minute potential difference fluctuations which are generated together with changes in the load current volume between each input and output of current buffers with switches CB1 to CBn.

Further, the technical idea of the present invention is not one which is limited to the concrete configuration examples and connection mode examples of the aforementioned working modes. Moreover, on the basis of the technical idea of the present invention, extensive application may be made by suitably modifying the aforementioned working modes.

E.g., in the case the main cause of the measurement error accompanying the insertion of current buffers with switches CB1 to CBn in the configuration shown in Fig. 3 cannot be disregarded, an added calibration function may be provided, as desired. Specifically, in order to calibrate the different variations in a measurement system comprising series resistances R1 to Rn and potential difference measuring portion 150, known currents are passed at several points in each range and measured with potential difference measuring portion 150, and the linearity correction amount and the offset correction amount are demanded in advance and saved as a table in a memory, which is not illustrated, so as to make the obtained measurement data correlate with known current values. Then, the actual unknown currents are measured and arithmetically processed by reading the corresponding correction amounts from the saved table. In this way, the main cause of the measurement error accompanying the different variations of a measurement system comprising current buffers with switches CB1 to CBn can be practically cancelled, so highly accurate measurement results are obtained,

and, additionally, the advantage is obtained that it is also possible to cancel component variations and aging.

Moreover, in the aforementioned configuration example in Fig. 3, the explanation was given with an embodiment using current buffers with switches CB1 to CBn, but range switching portion 210 shown in Fig. 8 may be used as desired. The current range switching portion 210 in Fig. 8 is composed of feedback operational amplifiers A31 to A3n, current buffers with switches CB1 to CBn connected to the outputs of the same, and series resistances R1 to Rn connected to the outputs of the same current buffers CB1 to CBn. The output of each current buffer with switch CBI is fed back to the inverted input of the corresponding feedback operational amplifier A3i. However, for the terminals of feedback operational amplifiers A31 to A3n, elements [measuring] at high impedance and not interfering with the measurements are applied. In this case, as a result of the output voltages Va1 to Van of the output terminal of each current buffer with switch CB1 to CBn being feedback controlled by feedback operational amplifiers A31 to A3n so as to match the input and output voltage Va, the advantage is obtained that the individual output voltage error causes of current buffers with switches CB1 to CBn can be cancelled.

20 Effects of the Invention

The present invention produces, drawing on the contents of the explanation given above, the effects set out below.

According to the configurations of the present invention mentioned above, the major advantage can be obtained that an implementation is possible with configuration elements that can be designed into an IC or an MCM, and it is also possible to implement a substantial reduction in size.

In addition, because the settling time of the ON/OFF control is less than several μ s, the advantage can also be obtained that it becomes possible to

switch with a remarkably high speed, compared to the past. In particular, in the case of an application to a voltage-impressed current measuring apparatus of a semiconductor test apparatus, for which there is the necessity to provide a number of channels, there can be obtained the major advantage that the
5 throughput of device tests in the DC test category can be improved. Moreover, there is the advantage that, as regards the drive current required for the ON/OFF control, very little is sufficient.

Accordingly, the technical effects as well the industrial effects of the present invention are large.